ALLAYING OF COAL DUST BY WATER INFUSION OF COAL IN PLACE IN THE LEADING COAL PRODUCING COUNTRIES OF THE WORLD

by

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

ILLUSTRATIONS

TABLE

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In particular, C. C. Newey, District Mining Engineer of the Joint Coal Board in Sydney, New South Wales, Australia, deserves special thanks. Mr. Newey, a world-renowned authority on coal-mining methods of dust suppression, gave generous help in the presentation of the water-infusion theory, which is given herein, and provided information he collected when infusion tests were made in the coal mines and beds of Australia. The writer had the good fortune to work with Mr. Newey during some of these tests, and the results convinced him that this method could be used advantageously in United States coal mines, particularly in the highly mechanized mines where dust liberated during conventional mining operations creates several notable hazards. Mr. Newey's guidance and information thus were very helpful in the course of the infusion tests recently conducted in the United States.

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SUMMARY

Excessive coal dust created and released during mining operations in pillars and faces of entries in some bituminous-coal mines in the eastern and western parts of the United States was allayed effectively by applying the water-infusion, or water-infiltration, method.

The infusion method consists of injecting water or a mixture of water and a wetting agent into coal pillars and faces of entries to abate dust, and to prevent the dispersion of small particles of dust normally created and released during subsequent operations of mining.

Dust counts were reduced to within safe limits by applying the water-infusion method in mine working places. In addition to reducing air-borne dust, water-infusion has been credited also with eliminating pillar heating and stopping one fire, thereby saving 700,000 tons of coal for uninterrupted mining operations. It was found that infiltration had important secondary advantages, as follows:

1. It partially degassed the working faces and thus reduced the possibility of ignition during other mining operations.

2. It caused incipient fracture of the coal, with consequent easing of cutting and, to a lesser extent, blasting.

The moisture added to the coal during infusion apparently had no effect on screening or on the marketing properties of the coal. Moisture was greatly reduced by evaporation during haulage.

It was indicated that the water-infusion method could be adopted for dust suppression in coal beds with similar physical structures to those

encountered in the Kenilworth, Lower Sunnyside, and Hiawatha coal beds in Utah; the Adaville coal bed in Wyoming; and the Beckley coal bed in West Virginia. Besides the nature of the coal bed, other important practical considerations affecting the application of the method were those of roof and floor; the location, spacing, and depth of the boreholes; and the pressure and rate of infusion of water or a mixture of water and wetting agent.

The water-infusion system was adopted in the pillar areas and faces of entries in some mines and was merged into the regular cycle of mining operations.

Because many of the leading coal-producing countries of the world have used the method quite extensively in some of their mines for several years, they have much more research data on the subject than we have in the United States. It is important to note that these countries claim excellent results in application of the water-infiltration method.

CHAPTER I

INTRODUCTION

Of the many problems confronting the coal-mining industry, none is more important than that of dust suppression. It is a human problem as well as one of production. It involves treatment of the dust, as it is formed during various mining operations, to render it harmless.

Dust-control problems have received attention throughout the world, and much research has been done to develop satisfactory dust-suppressing methods. In the coal-mining industry the dust problem is found in a peculiarly intractable form, inasmuch as the production and dispersal of dust is not restricted to any single phase of the operations of coal mining, but is usually associated with all of them.

Dust-control measures fall into the following two general classes:

1. Dust prevention.
2. Dust suppression.

It is not always possible to differentiate precisely between the two classes, but preventive methods imply a means of preventing spillage, giving attention to the design of machines and details, and substituting for shot firing, all of which aim at eliminating undue degradation of coal. Suppression methods include water infusion, wet cutting, using face sprays, wet drilling, dust traps, sprays at loader heads, sprays over loaded mine cars, and allaying dust on roadways.

The Problem

Statement of the problem

It is the purpose of this study (1) to present some of the results obtained during water-infusion tests made in several mines in the leading coal-producing countries of the world, and (2) to call attention to the possible application of the water-infusion method in more coal mines in the United States as an aid in suppressing dust.

Importance of the study

Considerable quantities of coal dust are made in mines during cutting, drilling, blasting, loading, and transportation of coal. When enough bituminous coal dust is suspended in the mine air to form a dense cloud, it presents a mine explosion hazard. There is considerable evidence that breathing air containing large amounts of suspended coal dust for long periods may lead to health impairment.[1] Air-borne coal dust reduces visibility and comfort and may be an indirect cause of accidents.

Definition of Terms Used

As an outgrowth of the realization that coal dust should be allayed at its source, many mines in the leading coal-producing countries of the world have installed dust-allaying equipment, and have adopted the water-infusion method of allaying dust at its source.

General theory of water infusion

Aim of infusion. The aim of water infusion is to control air-borne

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[1] H. N. Doyle and T. H. Noehren, Pulmonary Fibrosis in Soft Coal Miners: U. S. Department of Health, Education & Welfare, Public Health Bibliography Series No. 11, 1954, 59 pp.

dust production by increasing the surface moisture content of the coal before it is mined.

Mechanics of infusion. It has long been recognized that an obviously wet sample of coal contains "surface" or "adherent" moisture which covers the particle surfaces and lines the cracks, large and small, in the pieces of coal. The moisture held internally within the coal is known as "inherent" moisture. Until recently, a common method of differentiating between the "surface" and "inherent" moisture of a sample of coal was to determine the percentage of moisture remaining after the sample was dried in air, and also the percentage lost when it was heated at 105° centigrade for one hour. Moisture remaining in the coal after it was dried in air was misnamed "inherent" moisture; also, the percentage of moisture lost when the sample was heated to 105° centigrade was misnamed "total" moisture. The difference between them, or that percentage lost by air-drying, was misnamed "surface" or "adherent" moisture.

This practice, although still commonly followed, is unsatisfactory in certain respects. The chief difficulty arises from the fact that the "inherent"-moisture value so determined is not fixed, but varies for any given coal sample and depends on the relative humidity, that is, the partial pressure of the vapor in the air. If the air is nearly saturated, a higher value is obtained than results from drying the coal in very dry air.

Recent fundamental research on coal structure has provided a clearer understanding of the manner in which moisture is held internally in the coal. It is considered that coal is composed of sub-microscopic bodies called "micelles" in contact one with the other, but having still smaller spaces between them to which the name "intermicellar spaces" has been given. The whole structure is roughly analogous to a large number of extremely small, distorted marbles in close contact, the marbles representing the micelles and the spaces between them the intermicellar spaces. Moisture occupying these spaces is termed inherent moisture, and when all these spaces are filled the coal is said to be at its maximum inherent moisture value.

The maximum inherent moisture value of a coal is a definite property, like the percentage of fixed carbon or the coking index, and is related to the rank of the coal. In the case of low rank coals such as lignites, the intermicellar spaces are relatively open and the coal has a high maximum inherent moisture value up to 80 per cent. On the other hand, high rank bituminous coals may have maximum inherent moisture values as low as 1.71 per cent. In the latter case the micelles are believed to be crowded together, so that the intermicellar spaces are relatively small.

When a sample of coal, which has its maximum inherent moisture value and adherent moisture present as well, is allowed to dry in unsaturated air, all of the adherent and some of the inherent moisture evaporates. After air drying, the vapor pressure of the remaining inherent moisture is in equilibrium with the partial pressure of the vapor in the surrounding air. It can thus be seen that the old expression "inherent" moisture is really only a variable percentage of the actual maximum inherent moisture value.

If this same air-dried sample were allowed to stand in moist air or in water for a sufficient time, the intermicellar spaces would refill and the coal would regain its maximum inherent moisture value. The percentage adherent moisture of a coal sample so treated is the difference between its total moisture percentage and its maximum inherent moisture value. As the total moisture percentage of coal beds was normally higher than the maximum inherent moisture value, adherent moisture was normally present in place. Since the adherent moisture had obviously been present over extended periods, it could safely be assumed that the maximum inherent moisture demands of the coal were satisfied. The percentage adherent moisture could then be evaluated by difference.

The practical importance of the maximum inherent moisture determination lies in the fact that it enables the percentage adherent moisture to be determined. This latter figure is of prime importance in dust control, screenability, and similar investigations. Moisture increases the coherence between small particles if that moisture is present on the particle surfaces. But as the intermicellar spaces are far smaller than the smallest dust particle, it is probable that moisture held in them is not available for dust control. This was borne out by practical experience. A sample of subbituminous coal at its maximum inherent moisture value of 20 per cent can be as dusty as a sample of bituminous coal containing 1.71 per cent maximum inherent moisture and considerably dustier than the bituminous coal sample containing 2.71 per cent total moisture, that is, with 1.00 per cent adherent moisture.

Water forced into holes drilled into coal pillars traveled through the coal along the cleat planes naturally occurring within the coal. Coal that was strongly cleated at close intervals was expected to offer greater opportunity for water flow from the drill hole than a coal which was more massive in structure.

However, it was apparent that within the one area of coal, or even within the one pillar, there were zones which permitted greater water flows than others. This was believed to be due to the effects of roof pressures and roof-floor convergence.

Observation of a pillar indicated that the periphery of a pillar consisted of slabs broken away from the solid coal by parallel pressure cracks caused by mining. These cracks were more or less open and extended a distance into the pillar dependent mainly on the depth from the surface and the strength of the coal and associated strata. In a coal bed of the Southern coal field of New South Wales, Australia, a pillar measuring 150 feet by 180 feet and lying at a depth of approximately 1,500 feet from the surface commonly had pressure cracks extending as much as 10 feet into the pillar. If infusion holes drilled into such a pillar were not sealed beyond this broken periphery, the water escaped along the cracks to the floor. If holes were sealed beyond the periphery and infused, the infusion water did not take the shortest path to the outside of the pillar by way of the first cleat planes intersected by the hole. On the contrary, the water traveled through the cleats inside the pillar itself. This was due to the closing of the cleat within a zone of greater roof pressure adjacent to the roadways already driven.

Limitations of infusion. If the total moisture content of the coal in the pillar exceeded the maximum inherent moisture content characteristic of the coal, surface moisture was present and infusion of water was not likely to add more moisture to the surfaces of the coal.

If the total moisture content of the pillar coal was less than the maximum inherent moisture value of the coal, no surface moisture was present, because the maximum inherent moisture demand of the coal was satisfied first. Before moisture will remain on the coal surfaces, the inherent moisture demands of the coal must be satisfied. In parts of the Southern coal field in Australia, the maximum inherent moisture value exceeded the total moisture by 0.5 per cent. It was possible, therefore, to infuse a pillar and wet all the available coal surfaces only to have this surface moisture absorbed into the coal where it was not available for dust control on mining. Some of the failures experienced in pillar infiltration were attributed to this cause. In such cases it is recommended that the pillars be infused twice, first to raise the inherent moisture content and second, to supply the surface moisture. If pillars were infused continuously, for about two months or more, the excess loss of water would be tremendous.

Infusion of solid coal has not resulted in satisfactory control of dust produced by coal cutting operations. This is regarded as due to the rapid production of fine coal having a large surface area from the interior of the solid blocks of coal lying between the cleat planes. For similar reasons it is not likely that infiltration alone would result in satisfactory dust control when cutters are used in pillar coal.

The coal lying in the periphery of a pillar and broken from it by pressure cracks cannot be infused for reasons already discussed.

The coal immediately behind the crushed periphery of a pillar was highly stressed due to roof-floor convergence and could not be infused owing to the closure of the cleat.

Cases have been noted where whole pillars have resisted infusion at a pressure above that normally required. Such cases have been long and narrow roadway pillars in the final stages of pillar extraction in a section. They have been associated with difficult roof settling and with floor heave. This was considered due to the closure of the cleat over the whole area of the pillar.

Recommended Pillar-Infusion Practice. For convenience, the hole should be bored at about mid-height in the seam. However, where the seam shows a tendency to crush, which would result in the distortion and loss of holes so bored, it is advantageous to bore in any part of the seam which may be harder.

Very long holes are not desirable in pillar infiltration as length decreases the control over the distribution of the water.

In general, the worse the pillar conditions are with regard to roof conditions, floor heave, and crushing of the coal, the shorter the holes should be and the closer their spacing.

It is important that all flows into pillars be measured and controlled. Uncontrolled pillar infusion, at the least, leads to accumulations of water on the dip side and may have adverse effects on the stability of floor and roof strata. As pillars are likely to contain comparatively open breaks into which large quantities of water can pass at low pressure, it is necessary to measure flow and pressure when infusion is begun. This procedure indicates the rate of flow and pressure necessary to infuse the coal under normal conditions. The rate of flow should be checked at regular intervals as a "bump" in the coal can provide an open channel and increase the rate.

In pillar infiltration it is important to keep the amount of water used to a minimum and to insure its even distribution through the coal to be treated. As previously mentioned, it is desirable to infuse twice. The initial and major infusion should be done prior to splitting the pillar, that is, before the goaf line has advanced to the pillar. This should be followed by a second infusion during the actual extraction of the pillar to insure the presence of surface moisture on the surfaces of the cleat planes and other cracks within the coal.

The volume of water used in primary infusion should be in the ratio of 1 to 1-1/2 gallons for a ton of coal in the zone to be treated where the total moisture content of the coal is 0.5 per cent less than the maximum inherent-moisture value. Each hole should be individually metered. The secondary infusion should be in the ratio of 1/2 gallon for a ton of coal. The pillar should be reinfused only one lift in advance of extraction; or, where necessary, in the actual lift being worked on a day-to-day basis. As two, three, or four such holes may be infused for periods of 1 to 2 hours each day, one meter may be used per pillar.

High rates of flow encountered either at the start of infiltration or afterward should be taken to indicate that the water has found a low resistance path and is out of control. Throttling of the water at the pipeline valve to reduce the flow rate does not stop the water following the same path, and infusion of such a hole should be abandoned. That is, valves should be either open or closed.

The limited data available indicated that, with pressures in the range of 50 to 100 pounds per square inch, flows up to 30 gallons per hour were normal, that above 30 gallons per hour they were subject to suspicion, and that when flow reached 90 gallons per hour, infusion should be stopped.

Holes bored from an existing pillar rib must be sealed beyond the depth at which relatively open breaks occur. This may be as much as 9 or 10 feet. Holes bored in the more solid coal of a split or lift face may be sealed at a depth of 3 to 5 feet.

OBSERVED RESULTS OF THE WATER-INFUSION METHOD USED IN SOME COAL MINES IN AUSTRALIA

Mine A

General information

Mine A, in the Southern coal field of New South Wales, Australia produced 750 tons of coal daily in one loading shift. It was developed in the Bulli coal bed, which ranged from 6 to 9 feet in thickness and dipped about 3 degrees northwesterly in this mine. The coal was of bituminous rank and was very hard. The maximum overburden at the working faces was about 1,500 feet.

The proximate analysis of the coal was as follows:

	As submitted - percent
Moisture, at 105° C.	0.5
Volatile hydrocarbons	24.9
Fixed carbon	65.3
Ash	9.3
Total	100.0
B. T. U.'s	13,800

The ratio of volatile to total combustible, which is an index to the explosibility of coal dust, is shown by the following formula:

$$\frac{\text{Volatile matter}}{\text{Volatile matter plus fixed carbon}} = \frac{24.9}{24.9 + 65.3} = 0.276$$

The ratio of volatile to the total combustible of the coal in this mine is 0.276, indicating that the coal dust is explosive. Experiments[1] have shown that coal dusts with a volatile-combustible ratio of 0.12 or more are explosive.

The mine was developed by the bord-and-stall method and by a panel-and-entry system, and pillars were split with places 24 feet in width. Lifts from 15 to 21 feet were taken, working from the split to the gob. The formed pillars were 198 feet by 126 feet and 198 feet by 165 feet.

The mine was classified as gassy. Shortwall mining machines were used, and the coal was hand loaded into mine cars of one ton capacity.

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[1] Safety Course for Bituminous Coal Miners. United States Department of the Interior, Bureau of Mines, 1948. 94 pp.

Water infusion of coal pillars in Mine A.

Water, under pressure, was piped to all working places. The pillars were infiltrated with water prior to extraction.

At Mine A pressures used had varied from almost nil to 100 pounds per square inch, and average rates of flow over the total infusion time had varied from 1 to 145 gallons per hour. As the latter figure was an average rate over 4 days with pressures varying from 57 to 100 pounds per square inch, it was probable that even this high rate was exceeded at times. The former figure referred to a hole 42 feet long; the latter to a 120-foot hole.

Low rates of flows were not necessarily the result of low line pressures, but rather of high resistance offered to the passage of water within the coal. High rates of flow were associated with water running freely from the pillar. Generally, it was not possible to obtain any passage of water into pillars at pressures lower than 38 pounds per square inch.

Mine B

General information

Mine B, in the Southern coal field of New South Wales, Australia, produced 550 tons of coal daily in one loading shift. This mine, also developed in the Bulli coal bed, had physical conditions similar to the ones in Mine A.

Water infusion of coal pillars in Mine B

At Mine B the lowest rate of flow recorded was 0.9 gallons per hour at 100 pounds per square inch in a 20-foot hole. The highest rate of flow obtained was 120 gallons per hour at 100 pounds per square inch in a 44-foot hole. The latter flow was throttled back to 20 gallons per hour. The road on the dip side of this hole heaved shortly after infusion, broke the timber, and caused the roof to fall.

Mine C

General information

Mine C, in the Southern coal field of New South Wales, Australia, produced 1,000 tons of coal daily in one loading shift. Since this mine also was developed in the Bulli coal bed, it had physical conditions much like those in Mines A and B. Water infusion seals found suitable for pressures to 350 pounds per square inch were used in all three mines. Infusion holes were drilled with tungsten-carbide tipped bits having a diameter of 1-5/8 inches.

Water infusion of coal pillars in Mine C

At Mine C attempts were made to infuse pillar coal from two holes, one bored to a depth of 60 feet and the other to 20 feet. Only 40 to 50 gallons entered the former at 100 pounds per square inch, while none entered the latter at the same pressure.

CHAPTER II

REVIEW OF THE LITERATURE AND HISTORY

Rowland James[1] stated that the method of water infusion, which had been practiced for the first time in mines on the south coast of New South Wales, Australia in 1939, was introduced to the United Kingdom about 1942, in the coal mines of South Wales. There was evidence prior to 1942 that the mining industry in Britain was losing men at the rate of 7,000 per year as a result of silicosis and pneumoconiosis. As much as 90 per cent of such cases occurred in the South Wales mines. Actually, in some of these mines at this time the dust concentration in the atmosphere was so thick that it was impossible for a worker to see his hand at arm's length. Since 1942, the practice of infusing Britain's coal beds with water has been rapidly expanded. Now virtually all faces requiring dust-suppression treatment have been processed with water or an oil-and-water emulsion, and the threat of silicosis and pneumoconiosis has been alleviated.

Specifically, the chief benefits of the water-infusion method used in the coal mines of the United Kingdom are these:

1. The amount of air-borne dust was substantially reduced, as much as 66.5 to 92.5 per cent. This reduction was responsible for a definite

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[1] Rowland James, Report on Overseas Investigations into Methods of Working Thick Coal Seams - Solid Stowage - Mechanization - Practices Generally in Coal Mines - Oil from Coal and Amenities for Miners, 1946 (Canberra, Australia: Commonwealth of Australia Government Printer, 1946), pp. 29-33.

improvement in coal-face illumination, which aids visibility and therefore favorably affects safety conditions.

2. The coal was easier to mine.

3. The mine atmosphere was more refreshing and wholesome.

4. Judicious application of water had not affected the roof.

Anthracite mining officials in England have found that water injected under pressure into boreholes would, in time, seep through the fine cracks formed by slips and other fractures in the coal bed to such an extent that the dust in these beds would become moistened enough to prevent dispersal into the air during the subsequent mining operations of the coal.[1]

Water-infusion experiments have been made in mines in the Netherlands also. According to A. Horner[2], very high pressures of more than 20 atmospheres gage were sometimes needed for successful treatment of the coal. In cases where coal was easily infused with water no advantages could be found from the use of a tested wetting agent.

While most faces were susceptible to water treatment, there remained a hard core of problem faces, due to some factor, that did not respond to the established infusion methods. These faces needed special attention, which usually took the form of the application of a wetting agent.

Water-infusion tests were made with water and oil mixtures varying from between 4 per cent and 10 per cent of oil. These tests indicated that

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[1]J. Ivon Graham, The Iron and Coal Trades Review. Vol. CXLIX, No. 3985, July 14, 1944, pp. 45-47.

[2]A. Horner, The Suppression of Dust at the Source of Formation, 1952. (Geneva, Switzerland: International Labour Office Printer, 1952), pp. 5-24.

infusion efficiency could be improved by using a smaller quantity of water, and that a uniform rate of infusion could be maintained with pressures far less than for water alone. In some cases, a 60 per cent reduction in pressure was recorded. Perhaps of greater importance was the fact that the results were more lasting. It was found that oil continued to spread over the coal after infusion ceased, and that a fairly uniform layer of oil was present when slips or cleats were exposed after 3 days. The indication was that the treatment would have remained effective for a much longer period than if water alone had been used.

Numerous wetting agents were available. Experience has indicated that the efficiency of wetting agents varies for different coals; thus the choice of a wetting agent should be influenced by its affinity for the coal being treated. Wetting agents have been of particular value where roof conditions were difficult. Two of the main beneficial factors were the reduction of liquid needed for a given result and the reduced pressures necessary for percolation or infusion. These factors tended to reduce roof and floor penetration.

In some mines in Belgium, R. Ferre reports,[1] the water-infusion system of allaying coal dust was used to advantage. There was considerable decrease in air-borne dust in the working sections, and the coal in place was easier to mine after it was treated.

In fact, in certain Belgian coal beds the method was responsible for

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[1] R. Ferre, Water Infusion in a Vein, 1947 (Lievin, Belgium: Colliery of the Nord and Pas de Calais Basins, 1947), pp. 1-2 (Material translated from report written in the French language.)

a great reduction in the quantity of air-borne dust circulating in the working places.[1] The average daily production of coal per man in one of the mines was increased from 6 metric tons before the coal was infused, to 6-3/4 metric tons per man after infusion. The overall decrease in air-borne dust density in mines where the water-infiltration method was used varied from 50 to 75 per cent. It was also reported that the application of the method had no ill effects on the supporting characteristics of the mine roof.[2]

Official reports show that 17 per cent of the coal produced in underground mines in France[3] was mined after the coal was infused with water. When the decrease of air-borne dust in the active working places of the mines was measured by the thermic precipitator, it was found to vary from 70 to 90 per cent.

In 1948, while the writer was on a tour of mining duty for the Australian Government, he observed the method of water infusion in operation in the underground coal mines in New South Wales, Australia, for the purpose of allaying the dust formed in coal beds before it could become air-borne during subsequent mining operations.

At the coal faces in the mines in New South Wales, the dust that could

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[1]R. Ferre and J. Frere, The Struggle Against Dust, 1947 (Lievin, Belgium: Collieries of the Nord and Pas de Calais Basins, 1947), pp. 1-4. (Material translated from report written in French.)

[2]Ibid.

[3]R. Ferre and J. Frere, Water Infusion in Coal in French Coal Mines, 1951. Technical Information Bulletin No. 37, French Coal Mines, France: Government Printing Office, 1951, pp. 2-10. (Material translated from bulletin written in French.)

be dispersed came chiefly from two sources:

1. The dust formed on the slip faces of the coal in place and in the induced breaks in the coal bed due to strata movement.

2. The dust formed by the physical disintegration of coal during mining operations.

The mining officials and other personnel of the coal mining industry in Australia helpfully explained the system of water infusion to the writer and showed him the results obtained in the allaying of dust in their mines. The writer was much impressed with these demonstrated results.

It was from this experience and the observations made that the writer was convinced that water-infusion could be used effectively to allay dust in the coal mines in the United States. The problem of air-borne dust in our mines was equally as serious as it was in the Australian mines before the innovation of the water-infusion method.

The writer has supervised and helped with water-infusion experiments conducted in some mines in the United States.

CHAPTER III

RESULTS OF THE WATER-INFUSION METHOD USED IN SOME MINES IN THE UNITED STATES

Mine D

General information

Mine D is in Utah, and is developed in the Kenilworth coal bed, which ranges from 9 to 16 feet in thickness and dips about 5° north in this mine. The coal is of bituminous rank, is very hard, and contains an appreciable amount of resin. The maximum overburden at the present working faces is about 2,200 feet.

The proximate analyses of the coal were as follows:

	As submitted, per cent	moisture free, per cent
Moisture at 105° C.	2.8	-
Combustible volatile matter	43.8	45.0
Fixed carbon	48.4	49.9
Ash	5.0	5.1
	100.0	100.0
Sulfur	0.5 to 0.7 per cent	
B. T. U.'s	12,960	13,570

The ratio of volatile to the total combustible of the coal in this mine is 0.475, indicating that the coal dust is highly explosive.

The mine was developed by the room-and-pillar method and by a panel-and-entry system. Pillars were recovered by splitting them on the retreat. Entries were driven 14 to 20 feet wide and rooms 18 to 24 feet wide.

The mine was classified as gassy by the Safety Division of the Industrial Commission of Utah.

Electric power, 440 volts alternating current and 250 volts direct current, was used underground.

Mining equipment used in the working places of the pillar area of 1 and 2 west entries consisted of: 11-BU caterpillar-mounted loading machines; track-mounted universal mining machines; hand-held electrically-operated coal augers, which drilled holes 2-1/2 inches in diameter, all-steel mine cars having a capacity of 6 tons; and trolley and cable-reel electric locomotives.

The coal was blasted with sheathed permissible explosives.

<u>Water infusion of coal pillars</u>

A pillar section in 1 and 2 west entries off No. 4 slope was selected for water-infusion tests. This section of the mine was developed during the period 1943 to 1945; the pillars, therefore, had been standing for some time. As a result, the floor had heaved in some places to within 6 feet of the roof, the pillars were badly crushed, and much sloughing had occurred. The original coal height was about 16 feet. Heaving was in progress, requiring repeated bottom lifting during pillar recovery.

As it was elsewhere in the mine, water was piped under pressure to all working faces for use on cutting and loading machines, for washing down the face before shooting, for washing out drill holes, and for sprinkling the loose coal before and during loading. Sprays were also installed on all main partings and at other points along the main haulageways for sprinkling the tops of loaded mine cars.

Pillars that were infiltrated with water and water mixed with a wetting agent during various stages of the tests were diamond-shaped and were normally 57 feet by 124 feet in size. An individual pillar was mined by driving pockets approximately 25 feet wide across it, usually from the lower side, leaving 8-foot fenders.

Infusion boreholes normally were drilled on approximately the center lines of the pockets, usually from the higher side of the pillars, collared 4 feet below the roof, spaced longitudinally on about 20-foot centers, and drilled horizontally or diagonally upward to a depth of 35 feet. Since the coal bed dipped 5°, the boreholes were terminated at the top of the coal or as near the top as possible.

As a temporary expedient, water mixed with a wetting agent was injected into pillars through 1-1/4-inch pipes 20 feet long, connected to the sprinkler lines by hose. Pressures up to 270 pounds per square inch were used in the original holes, but experience indicated that such pressures were unnecessary; and consequently pressures of 50 to 63 pounds per square inch were used. These pressures were obtained by throttling with the pipeline valves.

The ends of the pipes were wound for a distance of 3 feet with brattice-cloth strips secured with friction tape. The pipes were pushed into the holes as far as possible and then were driven to a depth of about 15 feet with a cap piece. A special sleeve-type drill-hole adapter, which was screwed into boreholes about 10 feet from the collars of the holes, made a tight water seal.

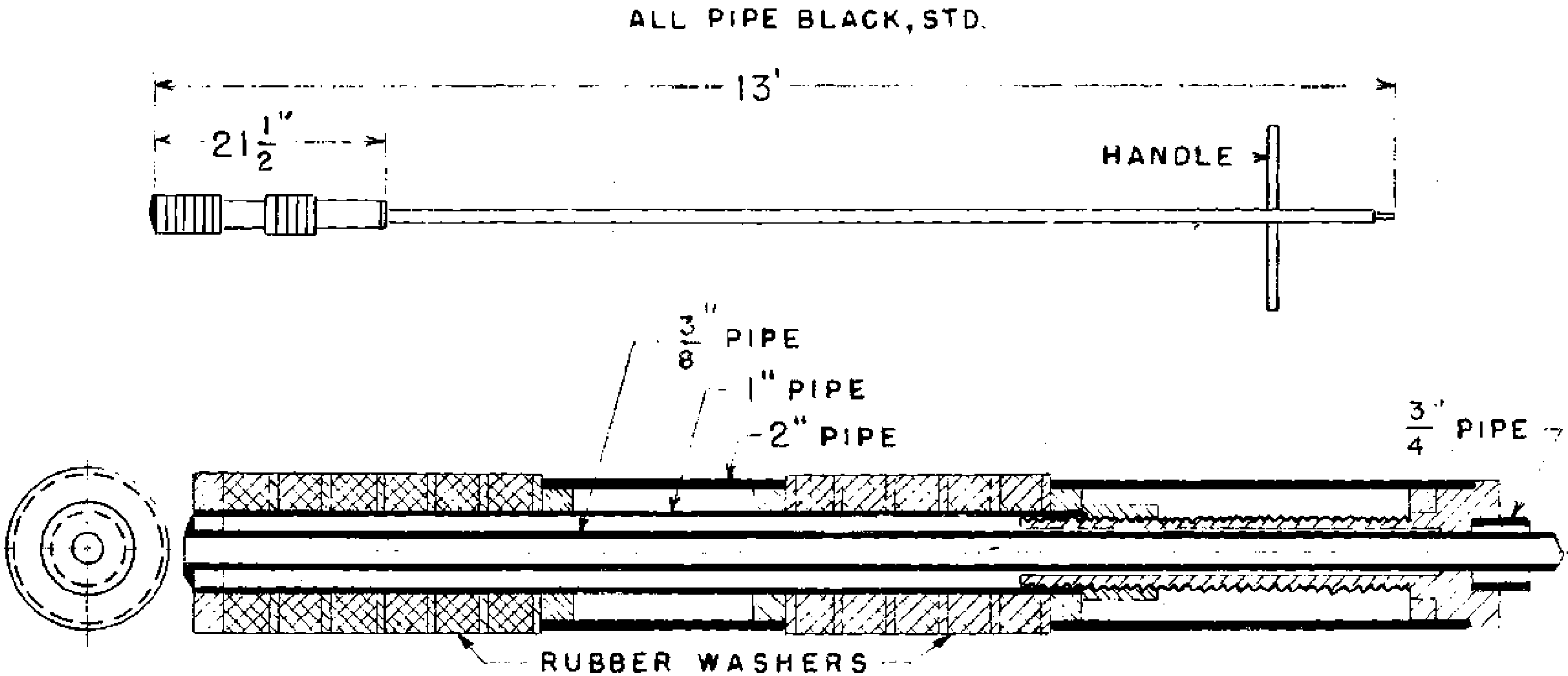

FIG. 1—SCHEMATIC SKETCH OF NEW TYPE OF WATER INFUSION SEAL USED DURING SOME WATER INFUSION TESTS.

New type of water-infusion seal

Observations made in Mine D revealed that the coal in many of the pillars was crushed to depths of 10 feet. The boreholes intended for infusion had to be sealed beyond the crushed coal to prevent water from leaking through the breaks or cracks.

A new type of water-infusion seal (Figure 1) was designed and used during recent tests in Mine D. Results were satisfactory when tests were made with the seal at various depths in the boreholes.

When the seal was inserted into a borehole to the desired depth, and tightened, it formed a watertight plug. The seal was tightened by turning the bar handle clockwise, thus reducing the short spaces between the rubber washers and the bronze washers and squeezing the rubber washers firmly against the bronze ones. The squeezing of the rubber washers made them expand and firmly grip the sides of the borehole. The outside pipe of the seal was moved forward over the stationary inside pipe by a pipe-screw thread and sleeve when the handle was turned clockwise.

A laboratory test was made by inserting the seal into a 2-1/2 inch pipe which had one end sealed off by a pipe plug. The handle of the outside pipe was turned clockwise manually as far as possible. The inside pipe of the seal at the free end was connected by pipe fittings to the discharge end of a small high-pressure, triplex-plunger pump, which was operated by a 1/2-horsepower electric motor. The pump was able to create hydraulic pressures up to 1,200 pounds per square inch. The water-infusion seal withstood hydraulic pressures up to 400 pounds per square inch before it began to slip out of the 2-1/2-inch pipe.

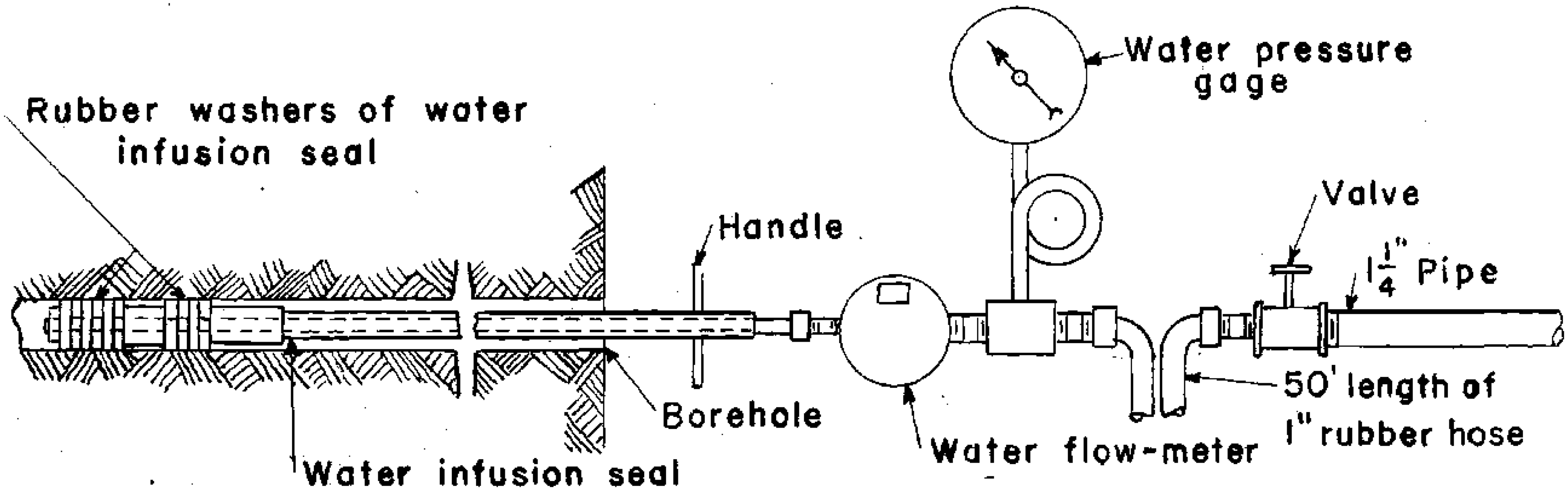

FIG. 2 — DETAILS OF CONNECTIONS OF WATER PRESSURE GAGE, WATER-FLOW METER, AND WATER INFUSION SEAL, AND THEIR RELATIVE POSITIONS IN WATER SYSTEM WHEN COAL IN PLACE WAS BEING INFUSED.

To remove the seal from a borehole after it was tightened, the bar handle was turned counterclockwise, releasing the horizontal pressure on the rubber washers.

Metering of solution flows and water pressures

Tests were made to determine in gallons per minute the flow of solution (water mixed with Aquadyne, a wetting agent) infiltrated under different hydraulic pressures into pillars through the water seal. Figure 2 illustrates details of connections of the water-pressure gage, the water-flow meter, and the water-infusion seal. It shows their relative positions in the water system when a pillar of coal was being infused.

During the infusion tests made in separate boreholes the hydraulic pressure ranged from nearly zero to 125 pounds per square inch. The quantity of the solution forced through the water-infusion seal under different hydraulic pressures in these boreholes ranged from 1/2 gallon to 20 gallons per minute. In Mine D as much as 1-1/2 gallons per minute was considered a normal flow under the hydraulic pressures ranging from 50 to 63 pounds per square inch. The amount of the solution in most of the tests was within normal limits. The rates were high (substantially above normal limits) when water ran freely from the pillars.

Water-infusion practices

In Mine D the water-infusion seals were placed in position, and the water was started about 30 days before the pillar was mined. The solution was kept running about a week, or sometimes more; then the infusion was stopped. When the first pocket was begun in a pillar the solution in that hole was also started and was kept running steadily until mining reached the hole.

To increase its effectiveness, the water used in infusion and for other dust-suppressing purposes at Mine D was treated with Aquadyne, dispensed from automatic proportioners. Results of the tests indicated that 1-1/4 to 2 gallons of solution were required to wet each ton of coal. The same amount was required to wet the coal after the pockets were driven across the pillars.

Results of water-infusion tests

The following was recommended: In bituminous-coal and lignite mines, the average full-shift concentration of atmospheric dust to which a workman may be exposed should not exceed 20 million particles per cubic foot of air, and the maximum concentration for any single operation should not exceed 40 million particles of dust per cubic foot. When the dust contains silica, not more than 5 million particles of silica dust per cubic foot of air should be present in the above limiting concentrations.

Dust counts made with a microprojector showed a reduction of 90.1 per cent in particles of dust measuring 10 microns or less in all similar mining operations such as drilling, shooting, and loading, including shooting of stumps. Dust counts before infusion ranged from 162.3 million particles of dust per cubic foot for loading and up to 575.7 and 678.6 million particles for cutting and for stump shooting, respectively. When the pillars were infused with water for 72 hours and then left standing for 60 days before mining operations were begun, the dust counts for drilling, shooting in regular faces and loading were materially reduced. However, the dust count of 30 million particles was below the recommended maximum.

When a wetting agent, Aquadyne, was used in the water and a pillar was infused for 14 days before and during extraction, the following dust counts were obtained: Drilling, 1.5 million particles per cubic foot; shooting (two tests), 9.73 and 11.86; loading 5.86; shooting out a stump, 18.3 million particles per cubic foot compared with 678.6 million without infusion and 416.3 million with 72-hour infusion with water. (See Table 1.)

In conjunction with the data in Table 1, the following information is listed to compare the results of the infusion method with the amount of air-borne dust created and released during the conventional system of wet-cutting coal and the mechanical loading of coal cut when wet.

The dust concentrations of air-borne samples collected in six bituminous coal mines during wet cutting of coal, by water forced through nozzles onto and around the cutter bars of the mining machines, ranged from 18.5 to 54.9 million particles per cubic foot of air.[1]

During mobile mechanical loading in four bituminous mines, after the coal was cut wet, the air-borne dust concentrations ranged from 18.7 to 63.5 million particles per cubic foot of air.[2]

Prevention of heating and firing of coal pillars

Water infusion was also credited with stopping a fire and eliminating pillar heating in a section of Mine D containing 700,000 tons of unmined

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[1] C. W. Owings, Control of Air-Borne Dust in Bituminous-Coal Mines in the United States; Proceedings, Fifth International Conference of Directors of Mine Safety Research (compiled by H. P. Greenwald): Bureau of Mines Bull. 489, 1950, pp. 183-196.

[2] Ibid.

Table 1. Relation of results obtained during some water-infusion tests

Operation	Column 1. Pillar not infused. Dust: m. p.p.c.f.[a]	Column 2. Pillar infused with water for 72 hrs. and then left standing 60 days before extracted. Dust: m. p.p.c.f.	Column 3. Pillar infused with water mixed with a wetting agent for 14 days prior to and during extraction. Dust: m. p.p.c.f.	Decrease of dust, in m.p.p. c.f., during similar mining operations from a variance in conditions, Column 1 minus Column 2	Decrease of dust, in m.p.p.c.f., during similar mining operations, from a variance in conditions, Column 1 minus Column 3	Per Cent decrease of dust in m.p.p. c.f. during similar mining operations: Columns 1 and 3
Drilling: electric coal auger	170.5	41.0	1.5	129.5	169.0	99.12
Shooting out of a stump	678.6	416.3	18.3	262.3	660.3	97.3
Blasting: sheathed permissible explosives used in 4 center and 7 top holes	393.6	152.4	11.86	241.2	381.74	96.98
Blasting: sheathed permissible explosives used in 8 bottom holes	216.1	127.1	9.73	88.9	206.37	95.5
Loading: mechanical	162.3	30.0	5.86	132.3	156.44	96.38
All operations suspended	2.8	1.68	.73	1.12	2.07	73.92
Section idle for 48 hours	1.9	1.1	.55	.8	1.35	71.5
Center-cutting[b]	575.7	-	-	-	-	-
Center-shearing[b]	247.9	-	-	-	-	-
Average decrease of m.p.p.c.f. of dust produced during all similar mining operations listed, Columns 1 and 3.						90.1

[a]Million particles per cubic foot

[b]It was not necessary to do any cutting during the extraction of pillars under conditions encountered during mining operations of pillar infused with water and pillar infused with water mixed with a wetting agent.

coal. The mine had suffered several fires in the past, and it was necessary to seal the sections in which the fires had originated.

At the time the infiltration tests were started, evidence of fire was discovered in the bottom of the sloughed coal and the crushed pillar in one part of the pillar section. As far as could be determined, the fire was a result of a "bounce" in one of the pillars that had not been infused, with the result that the coal in the low side was moved as much as 20 feet down the pitch. Friction, it was believed, ignited the coal. The sloughed coal was immediately loaded out and the pillar was drilled with infusion holes 30 feet long and 4 feet down from the top. Infiltrations of water mixed with Aquadyne cooled the pillar and extinguished the fire in a very short time, thus saving 700,000 tons of unmined coal for uninterrupted mining. With the fire so quickly extinguished by the application of the water-infusion method, the savings in money and time, as well as coal, were readily apparent.

All other pillars along the break line in the area were infused at the same time, and the temperature of the entire section, which had been uncomfortably warm, was considerably decreased.

RESULTS

As a result of observations made and of dust counts obtained during tests while mining an uninfused pillar, a pillar infused inadequately with water, and a pillar infused adequately with a mixture of water and a wetting agent, the following conclusions were drawn:

1. Dust could be allayed satisfactorily by water infiltration, espe-

cially if water mixed with a wetting agent was used as the infusion solution. Dust counts were reduced to within safe limits.

2. Approximately 70 to 90 per cent of the air-borne dust came from cracks in pillars and from thin crusts of crushed coal bordering these cracks. The amount of dust normally released was limited under extreme conditions (blasting out stumps) to about 18.3 million particles per cubic foot. Further, by washing out the dust in stump boreholes before blasting, the amount of dust normally released by blasting was reduced from about 18.3 million to about 12.6 million particles per cubic foot.

3. Application of the water-infusion method proved effective for fire-fighting purposes in Mine D when heat, supposedly caused by friction when a portion of a pillar was moved down the pitch by the forces of a bounce, started a smoldering fire in the pillar.

4. Efficiency and safe mining were increased because of better visibility when dust was allayed.

5. When numerous pillars were infused in a section, there was a marked decrease in temperature, which made conditions more comfortable for the workmen.

6. The water-infiltration method could be adapted for dust suppression in coal beds with structures similar to those encountered in the Mine D coal bed, especially in the pillar areas.

Water infusion was believed to have important secondary advantages, as follows:

(a) It partially degassed the working faces, thus reducing the hazard of ignition during mining.

(b) It caused incipient fracture of the coal with consequent easing of cutting, and to a lesser extent, blasting.

The moisture added to the coal during infusion had no adverse effect upon preparation or on the marketing properties of the Mine D coal. Moisture was greatly reduced by evaporation during haulage.

WATER-INFUSION TESTS IN OTHER COAL MINES IN THE WESTERN PART OF THE UNITED STATES

Water-infusion tests were conducted in six other coal mines in the Rocky Mountain coal fields. Separate coal beds, ranging from 7 to 62 feet in thickness, were worked in these mines. The tests indicated that the coal beds yielded readily to the water-infusion method of allaying dust in advance of other mining operations. The geological names of the coal beds were the Lower Sunnyside and the Hiawatha in Utah, and the Adaville in Wyoming.

During these water-infusion tests, the metering of water flows and hydraulic pressures were not recorded, nor were dust samples collected during mining operations before or after the pillars or working faces were infused with water.

The primary purpose of these tests was to determine whether these coal beds could be infused. When the working places were infiltrated, droplets of water appeared on the faces, which were said to be "sweating." Observations made during mining operations before and after the working places were infused revealed that there was a great reduction in the amount of air-borne dust concentrations after infusion.

The water was introduced into the working places through 1-1/4-inch pipes 20 feet long, connected to sprinkler lines by hose. About 3 feet of the ends of the pipes was wound with brattice-cloth strips secured with friction tape. The pipes were pushed into the holes as far as possible and then driven to a depth of about 15 feet with a cap piece. Wooden wedges wrapped with brattice cloth then were driven between the pipes and the circumferences of the holes at the collars, thereby forming a relatively tight seal for relatively low hydraulic pressures.

WATER-INFUSION TESTS IN THE APPALACHIAN COAL FIELD

Mine E

General information

The first infiltration tests in the Appalachian coal field were conducted in Mine E, which is located in West Virginia. Tests were also made in coal pillars and solid workings in this mine.

Some of the most difficult conditions encountered in coal mining were found in Mine E, which has experienced a number of explosions and fires since 1923.

There were six shafts in the mine: the Nos. 1 and 2 shafts were each 640 feet deep; the No. 3 shaft 580 feet deep; the No. 4 shaft 700 feet deep, and the Nos. 5 and 6 shafts 500 feet deep. The shafts opened into the Beckley low-volatile bituminous coal bed, which averaged 66 inches in thickness in working places. The coal dust in this mine was explosive, and the proximate analysis of the coal was as follows:

		As submitted, per cent
Moisture		2.6
Volatile matter		18.2
Fixed carbon		73.5
Ash		5.7
	Total	100.0
Sulfur		1.1 per cent
B. T. U.'s		14,280

The ratio of volatile to the total combustible of the coal in this mine was 0.1984, which indicated that the coal dust was explosive.

The mine was developed by a room-and-pillar method. Main entries were driven in sets of six, cross entries in sets of four at intervals of 2,700 and 3,000 feet, and room entries in pairs at intervals of 300 feet. Entries were driven 18 feet wide and rooms 20 feet wide. Crosscuts were made at intervals of about 80 feet. Pillars were extracted by the open-end method on retreat.

The immediate roof in some parts of the mine was shale ranging from 4 to 30 feet in thickness, which required careful and extensive timbering for safe support, and in the other parts of the mine the roof was sandstone several feet in thickness. The main roof was either shale or laminated sandstone, which often loosens on exposure. Mining was done under the immediate roof.

The mine was classified as gassy by the West Virginia Department of Mines. Ventilation was induced in the mine by four fans operated exhausting, circulating a total of about 900,000 cubic feet of air per minute at water-gage pressures of 6.5, 9.3, 5.9, and 8.5 inches, respectively. About 4,500,000 cubic feet of methane was liberated from the mine in 24 hours.

Electric power - 110, 220, and 2,300 volts alternating current and 250 volts direct current - was used underground.

The equipment used in the face areas included cutting machines, mobile loading machines, hand-held electric drills, and storage-battery locomotives, all of the permissible type.

Storage-battery locomotives hauled the coal from the face regions in cars of 4 tons capacity. Trolley locomotives transported the coal to the shaft bottom where it was hoisted to the surface in self-dumping skips.

Most of the coal was blasted on shift with Cardox, a permitted blasting device, fired with permissible units. Coal was also broken down with Airdox in the main west and 1 west main southwest sections of the mine. Some of the coal and rock was blasted on shift with permissible explosives.

Water-infusion of coal pillars and faces of entries

Officials of Mine E observed that water injected under pressure into boreholes both in pillars and in solid workings would, in time, seep through the fine cracks formed by slips and other fractures in the coal bed to such an extent that the dust in these places was moistened sufficiently to prevent dispersal into the air during the subsequent mining operations.

Tests were made with boreholes drilled horizontally to depths of 9 feet, collared in the middle of the coal bed, and spaced 12 feet apart along the long axes of the pillars. The pillars were about 50 feet by 70 feet in size. It required from 100 to 130 minutes to infiltrate sufficiently the coal between adjacent boreholes and to a depth of 6 feet beyond the end of each hole.

Likewise, in developing entries, one borehole was drilled horizontally to a depth of 9 feet in advance of each 18 foot face, and the borehole was collared in the middle of the coal bed. It required 120 to 150 minutes to infuse the desired amount of coal.

The hydraulic pressures used during the infiltration tests ranged from 60 to 75 pounds per square inch.

In the face of a room started in a new pillar section, a borehole was drilled 30 feet deep, and about 150 gallons of water were forced into it in one hour. Water was piped from the surface. After water had been forced into the borehole for one hour, the face of the room began to "sweat," proving that the water had dispersed through the coal.

The solid and pillar workings in this mine could be infiltrated readily. All tests made during mining operations in working places infused with water revealed a considerable reduction in the amount of dust raised in suspension after infusion. The mine was one of the few in the United States classed as ultragassy. It was necessary, therefore, to carefully dilute and render harmless the methane gas that was liberated during the drilling of long boreholes. Entrapped gas was also released during the infusion of the coal through the boreholes, so the working places had to be kept well ventilated.

CHAPTER IV

DISCUSSION

The water-infusion tests in the eight coal mines in the United States yielded results which compared favorably with those reported in coal mines in Australia, Belgium, France, the United Kingdom, and the Netherlands. Representative mining officials in these countries generously provided technical reports and other publications containing water-infusion data. With the aid of such information, it was possible to conduct the experiments in the United States with a minimum of trial-and-error procedure.

The applicability of water infusion in allaying coal dust before mining operations was determined predominantly by the physical nature of the coal bed. The eight mines in the United States which were subjected to experiment were operated in five different coal beds. In each bed, the unmined coal yielded readily to water infusion. However, where physical conditions in the coal differed within the same coal bed, varying rates of infusion were observed.

Dust Formation

It was common knowledge of those working in the eight coal mines that dusts of various sorts were created at many points and in a wide variety of circumstances. Fine coal dust was usually present along the planes of slips or fractures in the coal bed, and crushed coal bordering the slips or fractures was a very productive source of powdery coal. The work of dust suppression had to deal with dust formed by uncontrollable natural means in the coal beds before mining, as well as that created and released during mining.

Dust, to be controlled effectively, must be allayed at its source before it can become air-borne. It has been found that water alone or water mixed with a wetting agent injected under pressure into boreholes would, in time, seep through the fine cracks formed by slips or other fractures in the coal beds to such an extent that the dust would become moist enough to prevent dispersal into the air when the coal was mined.

The Coal-Dust Hazard

The interest manifested in the dust-suppression problem in the eight mines indicated the seriousness of the hazards involved, particularly when the dust had not been abated at its source. In addition to the dangers of explosion and health-impairment, there was a definite accident hazard, since visibility was so limited that the miners could not clearly see the ribs, the face of the coal, the condition of the roof overhead, and the moving parts of the various types of machinery, when the dust became air-borne in a dense cloud.

Dustiness Limits

Tests and observations have indicated that in bituminous coal and lignite mines in the United States, 40 million particles per cubic foot constituted a dusty atmosphere. It has been recommended[1] that the average

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[1] Owings, C. W., Control of Air-Borne Dust in Bituminous-Coal Mines in the United States: Bureau of Mines paper presented before the Fifth International Conference of Directors of Mine Safety Research, Central Experiment Station, Bureau of Mines, Pittsburgh, Pa., Sept. 20-25, 1948. pp. 1-10.

full-shift concentration of atmospheric dust to which a workman may be exposed should not exceed 20 million particles per cubic foot of air, and the maximum concentration for any single operation should not exceed 40 million particles of dust per cubic foot of air. When dust contained silica, not more than 5 million particles of silica dust per cubic foot of air should be present in the above limiting concentrations.

During the water-infusion experiments, it was found that dust concentrations could be kept below 20 million particles per cubic foot while the mining operations were in progress.

Size of Dust Particles

The size of dust particles varied greatly during the water-infusion experiments, but it was common practice among scientific organizations in the United States to consider only particles of dust of 10 microns or less in diameter, when making dust counts.[1] One micron is approximately one-twenty-five thousandth of an inch. During the air-dust surveys made in conjunction with some of the water-infusion experiments, the diameter of particles considered was 10 microns and less.

Description and Operation of Midget Impinger

The midget impinger dust-sampling apparatus was used to collect the air-borne dust samples taken during the various mining operations before and after the coal was infused. Its underlying principle was based on impinging and wetting dust particles by drawing the air through a nozzle at high velocity onto a smooth surface under a bubbling column of liquid,

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[1] Ibid.

where the dust particles were retained in isopropyl alcohol. The impinger consisted essentially of two parts: (1) a four-cylinder pump to draw the air to be sampled through the sampling device[1]; and (2) the sampling flask, which consisted of a container and an impinger tube. The bottom of the flask served as the impinger plate.

Number Concentration of Mine Atmospheric Dust

The air-borne coal-dust samples collected during some of the water-infusion experiments were analyzed for number concentration. To determine the amount of dust in the samples, each filled dust-counting cell[2] was placed on the stage of a microprojector, which was a microscope arranged to project images on a ruled translucent screen[3,4] for bright-field counting of dust in impinger samples[5,6]. The amount of dust in each sample was determined by counting the particles in a known volume of the impinger liquid.

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[1]Schrenk, H. H. and Feicht, Florence L., Bureau of Mines Midget Impinger: Bureau of Mines Inf. Circ. 7076, 1939, 7 pp.

[2]Brown, Carlton E., and Schrenk, H. H., A Technique for Use of the Impinger Method: Bureau of Mines Inf. Circ. 7026, 1938, 20 pp.

[3]Brown, Carlton E., and Yant, William P., The Microprojector for Determining Particle-Size Distribution and Number Concentration of Atmospheric Dust: Bureau of Mines Rept. of Investigations 3289, 1935, 8 pp.

[4]Brown, Carlton E., Midget Microprojector for Dust Determinations: Bureau of Mines Rept. of Investigations 3780, 1944, 14 pp.

[5]Brown, C. E., Baum, L. A. H., Yant, W. P., and Schrenk, H. H., Microprojection Method for Counting Impinger Dust Samples: Bureau of Mines Rept. of Investigations 3373, 1938, 9 pp.

[6]Brown, Carlton E., and Schrenk, H. H., op. cit.

Density of Dust Samples

The average density of the air-borne dust samples, collected in the course of mining operations before the coal was infused with water and water mixed with a wetting agent, was analyzed. The data are shown in column 1 of Table 1.

Collected dust samples were taken with a midget impinger from representative working places during complete mining cycles of dry operations, including cutting, drilling, blasting, and mechanical loading of the coal. Other samples were collected during practices and conditions thought pertinent for basic comparison, such as dust created and released by the shooting of stumps of coal and the amount of dust suspended in the mine atmosphere after mining operations were stopped for 5 minutes and for 48 hours. (See column 1 in Table 1.)

Air-borne dust samples were collected in the course of mining before the coal was infused, after the coal was infused with water alone, and after the coal was infused with water and a wetting agent. The dust-allaying facilities normally used during mining operations were dispensed with during the collecting of the air-borne dust samples under the aforementioned three conditions. This was done so that representative air-borne dust samples could be collected and so that the results of the dust counts of the samples would indicate the progress in dust reduction obtained by water infusion of coal alone. However, in the comparison experiments, it was necessary to do any cutting during the extraction of pillars under conditions encountered during mining operations of a pillar infused with water and a pillar infused with water mixed with a wetting agent. Probably infusion of the pillars aided in the loosening of the coal and made cutting or shearing of the coal unnecessary.

Table 1 is a correlation of the results of the water-infusion tests. It indicates the amount of dust created and released during various mining operations when pillars were not infused; were infused for 72 hours and left standing for 60 days before extraction of the pillars was begun; and were infused continuously with water mixed with a wetting agent each day for 14 days before extraction of the pillars and also during extraction of the pillars.

Wetting Agents

The wetting agents used were generally organic compounds of somewhat complex structures which, when added to water, enabled the water to wet materials that otherwise could be wetted only slowly or not at all.

The two wetting agents used during some of the water-infusion experiments were chemical concentrates that, when added in minute quantities to water, would cause the liquid mixture to penetrate and allay coal dust by producing almost instant dispersion of the liquid over the dust particles.

According to a statement made by the manufacturer of one of the wetting agents used, a 3-pound capsule would treat a minimum of 1,000 gallons of water and reduce surface tension from 72 to 30 dynes.[1]

The wetting power of the compound-water solution was based on the

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[1]Aquadyne Corporation, "Wet Water" in Mines and Stone Plants: Aquadyne, Coal Dust Control Publication.

reduction not only of the surface tension of the solution, but also of the interfacial tension between the coal and the liquid.

The wetting agents were added to the water used for infusion by automatic proportioners installed in branch pipelines off the main discharge water lines. Some of the proportioners were designed and constructed to withstand pressures up to 300 pounds per square inch.

No differentiation in wetting power among the various wetting agents was attempted during any of the water-infusion tests.

Partial Degassing of Unmined Coal

In many of the water-infusion reports of foreign countries, great importance was placed on the degassing of unmined coal by drilling water-infusion holes and injecting water through them into the coal bed in advance of mining operations.

The amount of methane gas given off at each borehole was not measured during the experiments. The main interest in regard to gas liberation in the places was to keep the gas diluted to below 1 per cent, a concentration that could not be detected with a permissible flame safety lamp. Moreover, mine officials in one of the mines reported that methane gas had not been detected in the working faces during the driving of pockets across pillars since water-infusion practices were started in the water-infusion area of the mine.

During the water-infusion experiments in an ultragassy coal mine, it was necessary to keep a close check on the amount of liberated methane gas during the drilling of the long boreholes and when water was injected through the holes into the coal bed in advance of mining operations. It was also necessary, at times, to increase the volume of air sweeping the working faces in order to keep the liberated gas diluted within safe limits. All gas tests were made with permissible flame safety lamps.

Temperature in Mine Workings Decreased

It was stated in some of the water-infusion reports of foreign countries that the temperature in the water-infusion areas of some of the mines was lowered generally about 1° centigrade, and a drop as great as 5° centigrade was reported.

In one of the sections of a mine where the adoption of a full-scale water-infusion schedule was performed, it was determined that the temperature of the mine return air from the water-infusion section was decreased on the average about 8° Fahrenheit (from what it had been before the water-infusion method was instituted in the mining areas).

Suggested Areas for Further Study

The primary objectives of the water-infusion experiments conducted in five coal beds in the United States were to determine whether the coals would yield to infusion, and whether the fine coal dust that was usually present along the planes of slips or fractures in the coal beds could be allayed by water-infusion before the dust became air-borne during subsequent mining operations.

During the experiments, it was found that water-infusion had some important secondary advantages; these advantages were obtained from deductions made from observations.

The present study suggested the need for further research on a scientific basis in the following areas:

1. More extensive research should be made into the possibility of degassing coal beds by infusing the coal beds with water or water mixed with a wetting agent.

2. Case research should be made as to the wetting power of a wide variety of wetting agents that are available in the United States. Laboratory tests might give a preliminary indication as to their suitability, but trials underground would be necessary to determine whether or not they would produce desired results in different coal beds.

3. Research should be conducted in the producing coal beds in the United States to determine their susceptibility to infusion.

4. Additional research should be made to determine the amount of incipient fracture of coal caused by infusing coal beds before mining operations.

(a) In England,[1] it was thought that the water-infusion method should be extended by creating a sudden high pressure in water-filled holes, whereby the slips and fractures in the coal beds, still filled with water, would be widened and extended. The coal would be loosened by this "pulsed infusion" to a condition suitable for easy mining by mechanical means or by hand. There were various ways of applying the "pulse" but a convenient method was to fire a charge of permitted explosive into the water-filled holes. This technique was known as "pulsed infusion shotfiring." In some of the mines in England where it was practiced, the cutting or shearing

[1] J. Hancock, W. Taylor and H. C. Grimshaw, Pulsed Infusion Shotfiring, Research Report No. 97, U. D. C. 622.235. 43:622.807.4, July 1954 (London, England: Ministry of Fuel and Power), pp. 1-21.

of the unmined coal was eliminated, since the coal was shattered or loosened sufficiently to be loaded by mechanical loading machines.

(b) In England, the water-infusion method has also been applied to the loosening of roof-rock strata. After the roof-rock strata was treated, fewer holes and smaller charges of explosives were found to be effective. Similar advantages from water infusion might, therefore, be expected in the loosening of floor or bottom-rock strata which have not developed excessive crack formation.

5. To deal with the problem of pneumoconiosis in this thesis would be beyond the scope of the study. However, many foreign countries have made intensive studies of it, and believe the use of water infusion in their coal mines has minimized or eliminated the incidence of this occupational disease. The subject is highly controversial among mining authorities in the leading coal producing countries of the world.

CHAPTER V

CONCLUSIONS

The infiltration or infusion method consisted of injecting water or water mixed with a wetting agent into coal in place to allay dust and to prevent the dispersion of small particles of dust in subsequent mining operations. In addition to reducing air-borne dust during all mining operations in all mines where tests were conducted, infusion in one mine was credited with eliminating pillar heating and stopping one fire, thus saving 700,000 tons of coal for uninterrupted mining operation.

As a result of observations made and of dust counts obtained during the water-infusion tests, the following conclusions were drawn:

1. Dust could be allayed satisfactorily by water infiltration, especially if water mixed with a wetting agent was used as the infusion solution. Dust counts could be reduced within recommended safe limits.

2. Approximately 70 to 90 per cent of the air-borne dust came from cracks in pillars and from thin crusts of crushed coal bordering these cracks. The amount of dust normally released could be limited, under extreme conditions (blasting out stumps) to about 18.3 million particles per cubic foot. Further, by washing out the dust in stump boreholes before blasting, the amount of dust normally released could be reduced from about 18.3 million to about 12.6 million particles per cubic foot.

3. The application of the water-infusion method proved to be effective for fire-fighting purposes under conditions similar to those encoun-

tered in one mine when heat, supposedly caused by friction when a portion of a pillar was moved down the pitch by the forces of a bounce, started a smoldering fire in the pillar.

4. Efficiency and safe mining operations were increased because of better visibility when dust was allayed.

5. When numerous pillars were infused in a section, there was a marked decrease in temperature, which made conditions more comfortable for the workmen.

6. The water-infiltration method discussed in this thesis can be adapted for dust suppression in coal beds having structures similar to those encountered in the Kenilworth, Lower Sunnyside, Hiawatha, Adaville and Beckley coal beds.

Water infusion was found to have secondary advantages, as follows:

(a) It caused incipient fracture of the coal, with consequent easing of cutting and, to a lesser extent, blasting.

(b) It partially degassed the working faces and thus reduced gas hazards during other mining operations.

During the drilling of long boreholes for water infusion in an ultra-gassy coal mine, extra safety precautions had to be taken to dilute and render harmless the methane gas liberated through the holes.

The moisture added to the coal during infusion had no adverse effect upon preparation or on the marketing properties of the coal. Moisture was reduced greatly by evaporation during transportation.

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